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(54) Title: COMPOSITIONS AND METHODS FOR REVERSE TRANSCRIPTASE-POLYMERASE CHAIN REACTION (RT-PCR)

(57) Abstract

The present invention is directed to compositions and methods useful for the amplification of nucleic acid molecules by reverse transcriptase-polymerase chain reaction (RT-PCR). Specifically, the invention provides compositions and methods for the amplification of nucleic acid molecules in a simplified one- or two-step RT-PCR procedure using combinations of reverse transcriptase and thermostable DNA polymerase enzymes in conjunction with sulfur-containing molecules or acetate-containing molecules (or combinations of such sulfur-containing molecules and acetate-containing molecules), and optionally bovine serum albumin. The invention thus facilitates the rapid and efficient amplification of nucleic acid molecules and the detection and quantitation of RNA molecules. The invention also is useful in the rapid production and amplification of cDNAs which may be used for a variety of industrial, medical and forensic purposes.

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Compositions and Methods for Reverse Transcriptase-Polymerase Chain Reaction (RT-PCR)

FIELD OF THE INVENTION

The present invention is in the fields of molecular and cellular biology.

5 The invention is particularly directed to compositions and methods useful for the amplification of nucleic acid molecules by reverse transcriptase-polymerase chain reaction (RT-PCR). Specifically, the invention provides compositions and methods for the amplification of nucleic acid molecules in a simplified one- or

10 two-step RT-PCR procedure using combinations of reverse transcriptase and thermostable DNA polymerase enzymes in conjunction with sulfur-containing molecules or acetate-containing molecules (or combinations of sulfur-containing molecules and acetate-containing molecules) and optionally bovine serum albumin. The invention thus facilitates the rapid and efficient amplification of nucleic acid molecules and the detection and quantitation of RNA molecules. The invention

15 also is useful in the rapid production and amplification of cDNAs (single-stranded and double-stranded) which may be used for a variety of industrial, medical and forensic purposes.

BACKGROUND OF THE INVENTION

Reverse Transcription of RNA

20 The term "reverse transcriptase" describes a class of polymerases characterized as RNA-dependent DNA polymerases. All known reverse transcriptases require a primer to synthesize a DNA transcript from an RNA template. Historically, reverse transcriptase has been used primarily to transcribe mRNA into cDNA which can then be cloned into a vector for further

25 manipulation.

Avian myoblastosis virus (AMV) reverse transcriptase was the first widely used RNA-dependent DNA polymerase (Verma, *Biochim. Biophys. Acta* 473:1

(1977)). The enzyme has 5'-3' RNA-directed DNA polymerase activity, 5'-3' DNA-directed DNA polymerase activity, and RNase H activity. RNase H is a processive 5' and 3' ribonuclease specific for the RNA strand for RNA-DNA hybrids (Perbal, *A Practical Guide to Molecular Cloning*, New York: Wiley & Sons (1984)). Errors in transcription cannot be corrected by reverse transcriptase because known viral reverse transcriptases lack the 3'-5' exonuclease activity necessary for proofreading (Saunders and Saunders, *Microbial Genetics Applied to Biotechnology*, London: Croom Helm (1987)). A detailed study of the activity of AMV reverse transcriptase and its associated RNase H activity has been presented by Berger *et al.*, *Biochemistry* 22:2365-2372 (1983).

Another reverse transcriptase which is used extensively in molecular biology is reverse transcriptase originating from Moloney murine leukemia virus (M-MLV). *See, e.g.*, Gerard, G.R., *DNA* 5:271-279 (1986) and Kotewicz, M.L., *et al.*, *Gene* 35:249-258 (1985). M-MLV reverse transcriptase substantially lacking in RNase H activity has also been described. *See, e.g.*, U.S. Patent No. 5,244,797.

PCR Amplification of RNA

Reverse transcriptases have been extensively used in reverse transcribing RNA prior to PCR amplification. This method, often referred to as RNA-PCR or RT-PCR, is widely used for detection and quantitation of RNA.

To attempt to address the technical problems often associated with RT-PCR, a number of protocols have been developed taking into account the three basic steps of the procedure: (a) the denaturation of RNA and the hybridization of reverse primer; (b) the synthesis of cDNA; and (c) PCR amplification. In the so-called "uncoupled" RT-PCR procedure (*e.g.*, two-step RT-PCR), reverse transcription is performed as an independent step using the optimal buffer condition for reverse transcriptase activity. Following cDNA synthesis, the

-3-

reaction is diluted to decrease $MgCl_2$ and deoxyribonucleoside triphosphate (dNTP) concentrations to conditions optimal for *Taq* DNA Polymerase activity, and PCR is carried out according to standard conditions (see U.S. Patent Nos. 4,683,195 and 4,683,202). By contrast, "coupled" RT-PCR methods use a common or compromised buffer for reverse transcriptase and *Taq* DNA Polymerase activities. In one version, the annealing of reverse primer is a separate step preceding the addition of enzymes, which are then added to the single reaction vessel. In another version, the reverse transcriptase activity is a component of the thermostable *Tth* DNA polymerase. Annealing and cDNA synthesis are performed in the presence of Mn^{++} , then PCR is carried out in the presence of Mg^{++} after the removal of Mn^{++} by a chelating agent. Finally, the "continuous" method (e.g., one-step RT-PCR) integrates the three RT-PCR steps into a single continuous reaction that avoids the opening of the reaction tube for component or enzyme addition. Continuous RT-PCR has been described as a single enzyme system using the reverse transcriptase activity of thermostable *Taq* DNA Polymerase and *Tth* polymerase and as a two-enzyme system using AMV-RT and *Taq* DNA Polymerase wherein the initial 65°C RNA denaturation step was omitted.

Attempts to streamline the process of RT-PCR have not been easy, and several reports have documented an interference between reverse transcriptase and thermostable DNA polymerase *Taq* when used in combination in a single tube RT-PCR resulting in low sensitivity or lack of results. For example, there has been at least one report of a general inhibition of *Taq* DNA polymerase when mixed with reverse transcriptases in one-step/one tube RT-PCR mixtures (Sellner, L.N., *et al.*, *Nucl. Acids Res.* 20(7):1487-1490 (1992)). This same report indicated that the inhibition was not limited to one type of RT: both AMV-RT and M-MLV-RT inhibited *Taq* DNA polymerase and limited the sensitivity of RT-PCR. Under the reaction conditions used in the Sellner *et al.* studies (67 mM Tris-HCl, pH 8.8, 17 mM $(NH_4)_2 SO_4$, 1 mM β -mercaptoethanol, 6 μ M EDTA, 0.2 mg/ml gelatin),

-4-

the degree of *Taq* polymerase inhibition was found to increase with increasing RT concentration, up to a ratio of approximately 3 units of RT:2 units of *Taq* DNA polymerase beyond which *Taq* polymerase was rendered completely inactive.

Other reports describe attempts to develop conditions for one-step RT-PCR reactions. For example, the use of AMV-RT for one-step RT-PCR in a buffer comprising 10 mM Tris-HCl, (pH 8.3), 50 mM KCl, 1.5 mM MgCl₂, and 0.01% gelatin has been reported (Aatsinki, J.T., *et al.*, *BioTechniques* 16(2):282-288 (1994)), while another report demonstrated one-step RT-PCR using a composition comprising AMV-RT and *Taq* DNA polymerase in a buffer consisting of 10 mM Tris-HCl, pH 8.3, 50 mM KCl, 0.01% gelatin and 1.5 mM MgCl₂ (Mallet, F., *et al.*, *BioTechniques* 18(4):678-687 (1995)). Under the reaction conditions used in the latter report, substitution of M-MLV-RT (RNase H⁺ or RNase H⁻ forms) for AMV-RT showed the same activity in the continuous RT-PCR reaction.

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BRIEF SUMMARY OF THE INVENTION

The present invention is generally directed to compositions and methods useful for one-step/one-tube RT-PCR, preferably using M-MLV-RT, or its RNase H-deficient ("RNase H⁻") derivatives, in combination with one or more DNA polymerases, preferably in the presence of sulfur-containing molecules or acetate-containing molecules (or combinations of sulfur-containing molecules and acetate-containing molecules) to relieve the inhibition of PCR often observed when using compositions comprising two or more enzymes having reverse transcriptase activity.

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In particular, the invention is directed to methods for amplifying a nucleic acid molecule comprising (a) mixing an RNA template with a composition comprising a Moloney murine leukemia virus (M-MLV) reverse transcriptase, which is preferably substantially reduced in RNase H activity and which is most

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preferably SuperScript I or SuperScript II, in combination with one or more DNA polymerases and one or more sulfur-containing molecules, such as one or more sulfur-containing buffers, wherein the concentration of sulfur is at least 18 mM, to form a mixture; and (b) incubating the mixture under conditions sufficient to amplify a DNA molecule complementary to all or a portion of the RNA template.

In a related aspect, the invention is directed to such methods wherein one or more acetate-containing molecules, such as one or more acetate-containing buffers, is substituted for or combined with the one or more sulfur-containing molecules or buffers in step (a) of the above-described methods, wherein the concentration of the one or more acetate-containing molecules is about 1 mM to about 500 mM. In preferred such methods, the DNA polymerases used are thermostable DNA polymerases, and most preferably *Tne*, *Tma*, *Taq*, *Pfu*, *Tth*, VENT, DEEPVENT, *Pwo*, *Tfl*, or a mutant, variant or derivative thereof; most preferred in this aspect of the invention is *Taq* DNA polymerase.

In other preferred aspects of the invention, the DNA polymerases may comprise a first DNA polymerase having 3' exonuclease activity, most preferably a DNA polymerase selected from the group consisting of *Pfu*, *Pwo*, DEEPVENT, VENT, *Tne*, *Tma*, *Kod*, and mutants, variants and derivatives thereof, and a second DNA polymerase having substantially reduced 3' exonuclease activity, most preferably a DNA polymerase selected from the group consisting of *Taq*, *Tfl*, *Tth*, and mutants, variants and derivatives thereof. In additional preferred aspects of the invention, the unit ratio of the reverse transcriptase to the DNA polymerases is from about 0.2:2 to about 500:2, and in particularly preferred such aspects the ratio is from about 0.5:2 to about 250:2 or greater than about 3:2.

In other preferred aspects of the invention, the concentration of the one or more sulfur-containing molecules is at least 18 mM, and more preferably about 20 mM to about 50 mM. The invention is also directed to such methods wherein the source of the sulfur-containing molecules is a buffer or a sulfur-containing salt which may be ammonium sulfate, magnesium sulfate, TRIS-sulfate, or manganese

sulfate, as well as other sulfur-containing buffers and salts that will be familiar to one of ordinary skill.

5 In other preferred aspects of the invention, the concentration of the one or more acetate-containing molecules is about 1 mM to about 500 mM, and more preferably about 5 mM to about 250 mM, about 10 mM to about 200 mM, about 25 mM to about 150 mM, about 50 mM to about 100 mM, or about 60 mM. The invention is also directed to such methods wherein the source of the acetate-containing molecules is a buffer or an acetate-containing salt which may be ammonium acetate, magnesium acetate, TRIS-acetate, or manganese acetate, as well as other acetate-containing buffers and salts that will be familiar to one of
10 ordinary skill.

The invention is also directed to such methods wherein the mixture further comprises one or more nucleotides, preferably deoxyribonucleoside triphosphates (most preferably dATP, dUTP, dTTP, dGTP or dCTP), dideoxyribonucleoside
15 triphosphates (most preferably ddATP, ddUTP, ddGTP, ddTTP or ddCTP) or derivatives thereof. Such nucleotides may optionally be detectably labeled (*e.g.* with a radioactive or nonradioactive detectable label).

The invention is also directed to such methods wherein the mixture further comprises one or more oligonucleotide primers, which are preferably an oligo(dT)
20 primers, random primers, arbitrary primers or target-specific primers, and which is more preferably a gene-specific primer.

The invention is also directed to such methods wherein the incubating step comprises (a) incubating the mixture at a temperature (most preferably a temperature from about 35°C to about 60°C) and for a time sufficient to make a
25 DNA molecule complementary to all or a portion of the RNA template; and (b) incubating the DNA molecule complementary to the RNA template at a temperature and for a time sufficient to amplify the DNA molecule, preferably via thermocycling, more preferably thermocycling comprising alternating heating and cooling of the mixture sufficient to amplify said DNA molecule, and most

preferably thermocycling comprising alternating from a first temperature range of from about 90°C to about 100°C, to a second temperature range of from about 40°C to about 75°C, preferably from about 65°C to about 75°C. In particularly preferred aspects of the invention, the thermocycling is performed greater than 10 times, more preferably greater than 20 times.

The invention is also directed to such methods wherein the amplification is not substantially inhibited.

The invention is also directed to methods for amplifying a nucleic acid molecule comprising (a) mixing an RNA template with a composition comprising a Moloney murine leukemia virus (M-MLV) reverse transcriptase, which is preferably substantially reduced in RNase H activity, in combination with one or more DNA polymerases (most preferably selected from the group consisting of *Tne*, *Tma*, *Taq*, *Pfu*, *Tth*, VENT, DEEPVENT, *Pwo*, *Tfl*, and mutants, variants and derivatives thereof), one or more sulfur-containing molecules and one or more potassium-containing molecules, to form a mixture; and (b) incubating the mixture under conditions sufficient to amplify a DNA molecule complementary to all or a portion of the RNA template. In a related aspect, the invention is directed to such methods wherein one or more acetate-containing molecules, such as one or more acetate-containing buffers, is substituted for or combined with the one or more sulfur-containing molecules or buffers in step (a) of the above-described methods.

The invention is also directed to methods for amplifying a nucleic acid molecule comprising (a) mixing an RNA template with a composition comprising a Moloney murine leukemic virus (M-MLV) reverse transcriptase and one or more DNA polymerases, wherein the unit ratio of the reverse transcriptase to the DNA polymerases is greater than 3:2, to form a mixture; and (b) incubating the mixture under conditions sufficient to amplify a DNA molecule complementary to all or a portion of the RNA template.

The invention is also directed to compositions comprising a Moloney Murine Leukemic virus (M-MLV) reverse transcriptase, one or more DNA polymerases and one or more sulfur-containing molecules (wherein the sulfur concentration is at least 18 mM) or one or more acetate-containing molecules (wherein the acetate concentration is about 1 mM to about 500 mM), or combinations of one or more sulfur-containing molecules and one or more acetate-containing molecules at the above concentrations.

The invention is also directed to compositions comprising a Moloney Murine Leukemic virus (M-MLV) reverse transcriptase, one or more DNA polymerases, one or more potassium-containing molecules and one or more sulfur-containing molecules (wherein the sulfur concentration is at least 18 mM) or one or more acetate-containing molecules (wherein the acetate concentration is about 1 mM to about 500 mM), or combinations of one or more sulfur-containing molecules and one or more acetate-containing molecules at the above concentrations.

The invention is also directed to compositions comprising a Moloney Murine leukemic virus (M-MLV) reverse transcriptase and one or more DNA polymerases, wherein the unit ratio of the reverse transcriptase to the DNA polymerases is greater than 3:2.

Other preferred embodiments of the present invention will be apparent to one of ordinary skill in light of the following drawings and description of the invention, and of the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a photograph of an ethidium bromide (EtdBr)-stained gel demonstrating the inhibition of RT-PCR by reverse transcriptase. Lanes 1, 10, 11 and 20 contain 100 bp DNA sizing ladders.

Figure 2A is photograph of an EtdBr-stained gel demonstrating the protective role of bovine serum albumin (BSA) in RT-PCR of β -actin mRNA from 100 pg of HeLa total mRNA template. Lane 1 contains a DNA sizing ladder, and the arrow indicates the 1026 bp β -actin target sequence.

5 **Figure 2B** is a photograph of an EtdBr-stained gel demonstrating the protective role of BSA in RT-PCR of CAT mRNA from 10^5 copies of CAT mRNA template. Lane 1 contains a DNA sizing ladder, and the arrow indicates the 653 bp CAT target sequence.

10 **Figure 3** is a photograph of an EtdBr-stained gel demonstrating the performance of various RTs in sulfate ion- or BSA-containing buffers. Lane 1: 100 bp DNA sizing ladder; Lanes 2-5: 5 units/reaction of AMV-RT; Lanes 6-9: 5 units/reaction of M-MLV-RT; Lanes 10-13: 5 units/reaction of M-MLV-RT (RNase H⁻). Arrow indicates 500 bp CAT target sequence.

15 **Figure 4** is a photograph of an EtdBr-stained gel demonstrating the effect of reverse transcription reaction temperature on RT-PCR product formation. Duplicate samples of 100 ng (lanes 1-6) or 10 ng (lanes 7-12) of total HeLa RNA were reverse transcribed at the indicated temperatures, and a 606 bp DNA polymerase III ϵ subunit target sequence (lanes 1-6) or a 253 bp β -actin target sequence (lanes 7-12) were amplified by PCR. M: DNA sizing markers.

20 **Figure 5** is a photograph of an EtdBr-stained gel demonstrating improved yield of RT-PCR products obtained by conducting the RT reaction at higher temperatures. Duplicate samples of 10 ng of tobacco total RNA (lanes 1-6) or of 100 ng of total HeLa RNA (lanes 7-12) were reverse transcribed at 45°C (lanes 1, 2, 7 and 8), 50°C (lanes 3, 4, 9 and 10) or 55°C (lanes 5, 6, 11 and 12), and a 500 bp GADPH target sequence (arrowhead; lanes 1-6) or a 1475 bp DNA polymerase III ϵ subunit target sequence (arrow; lanes 7-12) were amplified by PCR. M: DNA sizing markers; L: 100 bp nucleic acid sizing ladder.

25 **Figure 6** is a photograph of an EtdBr-stained gel demonstrating the sensitivity and efficiency of the invention in RT-PCR of large (2-3 kb) products.

A 2.78 kb tuberous sclerosis II fragment was amplified from varying amounts of total HeLa RNA that was reverse transcribed using the compositions of the invention without (lanes 1-6) or with (lanes 7-12) the addition of 1 μ l of ELONGASE Enzyme Mix, or using a RT kit from Supplier A (lanes 13-18). Lanes 1, 2, 7, 8, 13 and 14: 1 ng of HeLa RNA; Lanes 3, 4, 9, 10, 15 and 16: 10 ng of HeLa RNA; Lanes 5, 6, 11, 12, 17 and 18: 100 ng of HeLa RNA; M: DNA sizing markers.

Figure 7 is a photograph of an EtdBr-stained gel demonstrating the sensitivity and efficiency of the invention in RT-PCR of long (> 3 kb) products. 100 ng of total HeLa RNA was reverse transcribed using the compositions of the invention with the addition of 1 μ l of ELONGASE Enzyme Mix, and fragments of the adenomatous polyposis coli gene that were 7.3 kb (lanes 1, 2), 7.7 kb (lanes 3, 4) or 8.9 kb (lanes 5, 6) in size were amplified by PCR. M: DNA sizing markers (*Hind*III digest of λ DNA).

DETAILED DESCRIPTION OF THE INVENTION

Overview

The present invention is directed to compositions and methods for use in reverse transcriptase-polymerase chain reaction (RT-PCR) production and analysis of nucleic acids. In particular, the invention provides compositions comprising a variety of components in various combinations. Such components include one or more sulfur-containing molecules or one or more acetate-containing molecules (or combinations of one or more sulfur-containing molecules and one or more acetate-containing molecules), one or more enzymes having reverse transcriptase activity, one or more DNA polymerases, one or more primers, one or more nucleotides and a suitable buffer. These compositions may be used in the methods of the invention to produce, analyze, quantitate and otherwise manipulate nucleic acid molecules using a one- or two-step RT-PCR procedure.

Compositions

The buffer in the compositions of the invention provide appropriate pH and ionic conditions for the enzymes having reverse transcriptase activity and DNA polymerase enzymes. The nucleotides used in the compositions (*e.g.*, deoxyribonucleoside triphosphates (dNTPs)), and the primer nucleic acid molecules provide the substrates for synthesis or amplification of nucleic acid molecules in accordance with the invention. The compositions of the invention may also include inhibition-relieving reagents to assist in overcoming inhibition in RT-PCR reactions.

Buffer and Ionic Conditions

The buffer and ionic conditions of the present compositions have been optimized to relieve RT-mediated inhibition of RT-PCR. Preferred compositions of the invention comprise one or more sulfur-containing molecules, which provide sulfur in ionic form such as sulfate ions, sulfite ions, sulfonate ions (*e.g.*, *p*-toluenesulfonic acid) and the like. Additional preferred compositions of the invention comprise one or more acetate-containing molecules, or combinations of one or more sulfur-containing molecules and one or more acetate-containing molecules.

The sulfur-containing molecules should be formulated into the compositions to preferably provide a concentration of sulfur in the solution of at least 18 mM, more preferably a concentration of at least 19 mM and most preferably a concentration of at least 20 mM. Particularly preferred concentration ranges for sulfur in the present compositions include about 18 mM to about 500 mM, about 18 mM to about 150 mM, about 18 mM to about 100 mM, about 18 mM to about 75 mM, about 18 mM to about 50 mM or about 18 mM to about 40 mM, and most preferably about 18 mM to about 50 mM.

The sulfur-containing molecules are preferably formulated into the present compositions in the form of one or more salts or buffers. Examples of suitable sulfur-containing salts according to the invention include, but are not limited to, ammonium sulfate, magnesium sulfate, manganese sulfate, potassium sulfate, sodium sulfate and the like. Most preferred are ammonium sulfate, magnesium sulfate and manganese sulfate. Examples of suitable sulfur-containing buffers according to the invention include, but are not limited to, TRIS-sulfate and other sulfuric acid-based buffers, as well as sulfonic acid-based buffers such as AMPSO (3-[(1,1-dimethyl-2-hydroxyethyl)amino]-2-hydroxy-propanesulfonic acid), BES (N,N-bis[2-hydroxyethyl]-2-aminomethanesulfonic acid), MOPS (3-N-morpholino)-propanesulfonic acid), MOPSO (3-N-morpholino)-2-hydroxypropanesulfonic acid, TES (2-[[tris-(hydroxymethyl)-methyl]amino]ethanesulfonic acid), HEPES (N-2-hydroxyethylpiperazine-N'-2-ethansulfonic acid), HEPPS (N-2-hydroxyethylpiperazine-N'-3-propanesulfonic acid), HEPPSO (N-2-hydroxyethylpiperazine-N'-2-hydroxypropanesulfonic acid), TAPS (TES (3-[[tris-(hydroxymethyl)methyl]amino]propanesulfonic acid), CHES (2-(N-cyclo-hexylamino)ethanesulfonic acid), MES (2-N-morpholino)ethanesulfonic acid, PIPES (piperazine-N,N'-bis-2-ethanesulfonic acid), POPSO (piperazine-N,N'-bis[2-hydroxy]propanesulfonic acid), TAPS (N-tris[hydroxymethyl]methyl-3-aminopropanesulfonic acid), TAPSO (3-[N-tris{hydroxymethyl}methylamino]-2-hydroxypropanesulfonic acid), ACES (N-2-acetamide-2-aminoethane sulfonic acid), DIPSO (3-[N,N-bis(2-hydroxyethyl)amino]-2-hydroxypropanesulfonic acid), CAPSO (3-[cyclohexylamino]-2-hydroxy-1-propanesulfonic acid) and CAPS (3-[cyclohexylamino]propanesulfonic acid). Other sulfur-containing ionic salts and buffers, and other sulfur-containing molecules, suitable for use in the compositions of the invention will be apparent to one of ordinary skill in the art.

The acetate-containing molecules should be formulated into the compositions to preferably provide a concentration of acetate ion in the solution

of about 1 mM to about 500 mM. Particularly preferred concentration ranges for acetate ion in the present compositions include about 1 mM to about 500 mM, about 5 mM to about 250 mM, about 10 mM to about 200 mM, about 25 mM to about 150 mM, about 50 mM to about 100 mM, or about 60 mM.

5 The acetate-containing molecules are preferably formulated into the present compositions in the form of one or more salts or buffers. Examples of suitable acetate-containing salts according to the invention include, but are not limited to, ammonium acetate, magnesium acetate, manganese acetate, potassium acetate, sodium acetate and the like. Examples of suitable acetate-containing
10 buffers according to the invention include, but are not limited to, TRIS-acetate (tris[hydroxymethyl]aminomethane acetate), ADA (N-[2-acetamido]-2-iminodiacetic acid), and imidazole acetate (2-hydroxy-3-[4-imidazolyl]-propionic acid).

 In accordance with the invention, one or more potassium-containing
15 molecules may be formulated into the present compositions to substitute for, and thereby reduce the concentration requirement for, sulfur. In this aspect of the invention, the addition of both sulfur-containing molecules and potassium-containing molecules decreases the concentration requirement for sulfur by about 13-75%, preferably by about 25-50%. For example, when potassium-containing
20 molecules are formulated into the present compositions, the concentration of sulfur-containing molecules may be reduced from about 18 mM to about 2-14 mM, or preferably to about 4-9 mM. It will be understood, of course, that the one or more potassium ions may also be used in the above-described compositions of the invention that contain one or more acetate-containing
25 molecules instead of, or in addition to, the one or more sulfur-containing molecules.

 The potassium-containing molecules should be formulated into the compositions at a preferred concentration of at least 2 mM, preferably at least 5 mM, still more preferably at least 10 mM, and most preferably at least 20 mM.

Particularly preferred concentration ranges of potassium-containing molecules in the present compositions include about 2 mM to about 500 mM, about 2 mM to about 200 mM, about 2 mM to about 100 mM, about 2 mM to about 75 mM, about 2 mM to about 50 mM, about 2 mM to about 40 mM, about 2 mM to about 30 mM, about 2 mM to about 20 mM and about 2 mM to about 10 mM.

The potassium-containing molecules are preferably formulated into the present compositions in the form of one or more salts or buffers. Examples of suitable potassium salts according to the invention include, but are not limited to, potassium sulfate, potassium sulfite, potassium chloride, potassium nitrate and the like. Most preferred are potassium chloride, potassium sulfate and potassium acetate. Preferred potassium buffers according to the invention include, but are not limited to, potassium phosphate (monobasic), potassium phosphate (dibasic) and the like. Other potassium salts and buffers, and other potassium-containing molecules, suitable for use in the present compositions will be apparent to one of ordinary skill in the art.

Molecules and buffers containing sulfur, acetate or potassium that are suitable for use in the present compositions are available commercially from a wide variety of sources, *e.g.*, from Sigma (St. Louis, Missouri).

Reverse Transcriptase Enzymes

The compositions of the present invention also comprise enzymes having reverse transcriptase activity. According to the present invention, the enzymes having reverse transcriptase activity are Moloney Murine Leukemia Virus (M-MLV) reverse transcriptases. Preferred enzymes for use in the invention include those that are substantially reduced in RNase H activity. By an enzyme "substantially reduced in RNase H activity" is meant that the enzyme has less than about 20%, more preferably less than about 15%, 10% or 5%, and most preferably less than about 2%, of the RNase H activity of a wildtype or RNase H⁺ enzyme such as wildtype M-MLV reverse transcriptase. The RNase H activity may be

determined by a variety of assays, such as those described, for example, in U.S. Patent No. 5,244,797, in Kotewicz, M.L., *et al.*, *Nucl. Acids Res.* 16:265 (1988) and in Gerard, G.F., *et al.*, *FOCUS* 14(5):91 (1992), the disclosures of all of which are fully incorporated herein by reference.

5 Particularly preferred enzymes for use in the invention include, but are not limited to, M-MLV reverse transcriptase (RNase H⁻ or substantially reduced in RNase H activity), and RSV reverse transcriptase (RNase H⁻ or substantially reduced in RNase H activity). Enzymes having reverse transcriptase activity are commercially available (for example, SUPERScript™, SUPERScript II™ and
10 M-MLV, available from Life Technologies, Inc.; Rockville, Maryland).

DNA Polymerases

The compositions of the invention also comprise one or more DNA polymerases, which are preferably thermostable DNA polymerases. These DNA polymerases may be isolated from natural or recombinant sources, by techniques
15 that are well-known in the art (*See* WO 92/06200, U.S. Patent Nos. 5,455,170 and 5,466,591, WO 96/10640 and U.S. Patent Application No. 08/370,190, filed January 9, 1995, the disclosures of all of which are incorporated herein by reference), from a variety of thermophilic bacteria that are available commercially (for example, from American Type Culture Collection, Rockville, Maryland) or
20 may be obtained by recombinant DNA techniques (*see, e.g.*, WO 96/10640 and U.S. Patent Application No. 08/370,190, filed January 9, 1995). Suitable for use as sources of thermostable polymerases or the genes thereof for expression in recombinant systems are the thermophilic bacteria *Thermus thermophilus*, *Thermococcus litoralis*, *Pyrococcus furiosus*, *Pyrococcus woosii* and other
25 species of the *Pyrococcus* genus, *Bacillus sterothermophilus*, *Sulfolobus acidocaldarius*, *Thermoplasma acidophilum*, *Thermus flavus*, *Thermus ruber*, *Thermus brockianus*, *Thermotoga neapolitana*, *Thermotoga maritima* and other species of the *Thermotoga* genus, and *Methanobacterium thermoautotrophicum*,

and mutants, variants or derivatives thereof. It is to be understood, however, that thermostable DNA polymerases from other organisms may also be used in the present invention without departing from the scope or preferred embodiments thereof. As an alternative to isolation, thermostable DNA polymerases are
5 available commercially from, for example, Life Technologies, Inc. (Rockville, Maryland), New England BioLabs (Beverly, Massachusetts), Finnzymes Oy (Espoo, Finland), Stratagene (La Jolla, California), Boehringer Mannheim Biochemicals (Indianapolis, Indiana) and Perkin Elmer Cetus (Norwalk, Connecticut).

10 Particularly preferred thermostable DNA polymerases for use in the compositions and methods of the present invention include, but are not limited to, *Taq*, *Tne*, *Tma*, *Tli*/VENT™, DEEPVENT™, *Pfu*, *Pwo*, *Tfi* or *Tth* DNA polymerases, or mutants or derivatives thereof. *Taq* DNA polymerase is commercially available, for example from Life Technologies, Inc. (Rockville,
15 Maryland), or may be isolated from its natural source, the thermophilic bacterium *Thermus aquaticus*, as described previously (U.S. Patent Nos. 4,889,818 and 4,965,188). *Tne* DNA polymerase may be isolated from its natural source, the thermophilic bacterium *Thermotoga neapolitana* (See WO 96/10640 and U.S. Patent Application No. 08/370,190, filed January 9, 1995), and *Tma* DNA
20 polymerase from its natural source, the thermophilic bacterium *Thermotoga maritima* (See U. S. Patent No. 5,374,553, the disclosure of which is incorporated herein by reference). Methods for producing mutants and derivatives of thermophilic DNA polymerases, particularly of *Tne* and *Tma* polymerases, are disclosed in co-pending U.S. Patent Application No. 08/689,807 of Deb K.
25 Chatterjee, and in co-pending U.S. Patent Application No. 08/689,818 of Deb K. Chatterjee and A. John Hughes, both filed September 6, 1996, which are incorporated by reference herein in their entirety. *Tfi*, *Tli*/VENT™ and DEEPVENT™ are available commercially (e.g., from New England BioLabs, Beverly, Massachusetts), or may be produced as described (Bej, A.K., and

Mahbubani, M.H., in: *PCR Technology: Current Innovations*, Griffin, H.G., and Griffin, A.M., eds., CRC Press, pp. 219-237 (1994) for *Tli*/VENT™; Flaman, J.-M., et al., *Nucl. Acids Res.* 22(15):3259-3260 (1994) for DEEPVENT™).
Thermostable DNA polymerases are preferably added to the present compositions
5 at a final concentration in solution of about 0.1-200 units per milliliter, about 0.1-50 units per milliliter, about 0.1-40 units per milliliter, about 0.1-36 units per milliliter, about 0.1-34 units per milliliter, about 0.1-32 units per milliliter, about 0.1-30 units per milliliter, or about 0.1-20 units per milliliter, and most preferably at a concentration of about 20 units per milliliter.

10 In preferred compositions of the invention, the concentration of DNA polymerases is determined as a ratio of the concentration of the enzymes having reverse transcriptase activity. Thus, in particularly preferred compositions the unit ratio of the reverse transcriptase enzymes to the DNA polymerase enzymes ranges from about 0.2:2 to about 500:2, preferably from about 0.5:2 to about 250:2 and
15 most preferably a ratio of greater than 3:2. Of course, other suitable ratios of unit activities of reverse transcriptase enzymes to DNA polymerases suitable for use in the invention will be apparent to one of ordinary skill in the art.

Inhibition-Relieving Reagents

20 In accordance with the methods of the invention, one or more additional inhibition-relieving agents may optionally be added to the present compositions to assist in overcoming the inhibition of RT-PCR reactions by RTs such as M-MLV RT. Preferred inhibition-relieving agents for use in the present compositions include peptides, polypeptides and proteins such as (but not limited to) human
25 serum albumin, bovine serum albumin, ovalbumin, Albumax, casein, gelatin, collagen, globulin, lysozyme, transferrin, myoglobin, hemoglobin, α -lactalbumin, fumarase, glyceraldehyde-3-phosphate dehydrogenase (GAPDH), amyloglucosidase, carbonic anhydrase, β -lactoglobulin, aprotinin, soybean trypsin inhibitor, trypsinogen, phosphorylase b, myosin, actin, β -galactosidase, catalase,

tryptic soy digests, tryptose, lectins and the like, or fragments or derivatives thereof. Particularly preferred for use in the compositions and methods of the invention are bovine serum albumin, human serum albumin, Albumax and casein. Peptides, polypeptides or proteins are preferably added to the compositions to
5 give a final concentration in the solution of about 0.01 to about 100 µg/ml, preferably about 0.1 to about 100 µg/ml, more preferably about 1 to about 50 µg/ml and most preferably about 2 to about 20 µg/ml.

dNTPs

The compositions of the invention further comprise one or more
10 nucleotides (*e.g.*, deoxynucleoside triphosphates (dNTPs)). The nucleotide components of the present compositions serve as the "building blocks" for newly synthesized nucleic acids, being incorporated therein by the action of the reverse transcriptases or DNA polymerases. Examples of nucleotides suitable for use in the present compositions include, but are not limited to, dUTP, dATP, dTTP,
15 dCTP, dGTP, dITP, 7-deaza-dGTP, α-thio-dATP, α-thio-dTTP, α-thio-dGTP, α-thio-dCTP or derivatives thereof, all of which are available commercially from sources including Life Technologies, Inc. (Rockville, Maryland), New England BioLabs (Beverly, Massachusetts) and Sigma Chemical Company (Saint Louis, Missouri). The dNTPs may be unlabeled, or they may be detectably labeled by
20 coupling them by methods known in the art with radioisotopes (*e.g.*, ³H, ¹⁴C, ³²P or ³⁵S), vitamins (*e.g.*, biotin), fluorescent moieties (*e.g.*, fluorescein, rhodamine, Texas Red, or phycoerythrin), chemiluminescent labels, dioxigenin and the like. Labeled dNTPs may also be obtained commercially, for example from Life
25 Technologies, Inc. (Rockville, Maryland) or Sigma Chemical Company (Saint Louis, Missouri). In the present compositions, the dNTPs are added to give a working concentration of each dNTP of about 10-1000 micromolar, about 10-500 micromolar, about 10-250 micromolar, or about 10-100 micromolar, and most preferably a concentration of about 100 micromolar.

Primers

In addition to nucleotides, the present compositions comprise one or more primers which facilitate the synthesis of a first DNA molecule complementary to all or a portion of an RNA template (*e.g.*, a single-stranded cDNA molecule).
5 Such primers may also be used to synthesize a DNA molecule complementary to all or a portion of the first DNA molecule, thereby forming a double-stranded cDNA molecule. Additionally, these primers may be used in amplifying nucleic acid molecules in accordance with the invention. Such primers include, but are not limited to, target-specific primers (which are preferably gene-specific primers),
10 oligo(dT) primers, random primers or arbitrary primers. Additional primers that may be used for amplification of the DNA molecules according to the methods of the invention will be apparent to one of ordinary skill in the art.

Methods of RT-PCR

In the RT-PCR reaction, the reaction mixtures are incubated at a
15 temperature sufficient to synthesize a DNA molecule complementary to all or portion of the RNA template. Such conditions typically range from about 20°C to 75°C, more preferably from about 35°C to 60°C and most preferably from about 45°C to about 55°C. After the reverse transcription reaction, the reaction is incubated at a temperature sufficient to amplify the synthesized DNA molecule.
20 Preferably the amplification is accomplished via one or more polymerase chain reactions (PCRs). Preferred conditions for amplification comprise thermocycling, which may comprise alternating heating and cooling of the mixture sufficient to amplify the DNA molecule and which most preferably comprises alternating from a first temperature range of from about 90°C to about 100°C, to a second
25 temperature range of from about 45°C to about 75°C, more preferably from about 50°C to about 75°C or from about 55°C to about 75°C, and most preferably from about 65°C to about 75°C. According to the invention, the thermocycling

-20-

may be performed any number of times, preferably from about 5 to about 80 times, more preferably greater than about 10 times and most preferably greater than about 20 times.

The compositions and methods of the present invention may also be used for the production, analysis and quantitation of large nucleic acid molecules (*e.g.*, by "long PCR" or "long RT-PCR"), preferably nucleic acid molecules that are larger than about 4-8 kilobases in size, more preferably larger than about 5-7 kilobases in size, and most preferably nucleic acid molecules that are larger than about 7 kilobases in size. In this aspect of the invention, combinations of DNA polymerases, preferably mixtures of one or more DNA polymerases lacking 3'-5' exonuclease activity (*i.e.*, a "3' exo⁻" polymerase) with one or more DNA polymerases having 3'-5' exonuclease activity (*i.e.*, a "3' exo⁺" polymerase), may be added to the compositions of the invention (*see* U.S. Patent No. 5,436,149; *see also* co-pending U.S. Patent Application No. 08/801,720, of Ayoub Rashtchian and Joseph Solus, filed February 14, 1997, and the co-pending U.S. Patent Application of Ayoub Rashtchian and Joseph Solus entitled "Stable Compositions for Nucleic Acid Amplification and Sequencing," filed March 27, 1998, the disclosures of all of which are incorporated herein in their entireties). Preferred 3' exo⁻ and 3' exo⁺ polymerases for use in this aspect of the invention are thermostable 3' exo⁻ and 3' exo⁺ polymerases. Particularly preferred 3' exo⁻ polymerases include, but are not limited to, *Taq*, *Tne*(exo⁻), *Tma*(exo⁻), *VENT*(exo⁻)TM, *DEEPVENT*(exo⁻)TM, *Pfu* (exo⁻) and *Pwo*(exo⁻) polymerases, or mutants, variants or derivatives thereof, which are preferably added to the compositions of the invention at a concentration in the solution of about 0.1-200 units per milliliter, about 0.1-50 units per milliliter, about 0.1-40 units per milliliter, about 0.1-36 units per milliliter, about 0.1-34 units per milliliter, about 0.1-32 units per milliliter, about 0.1-30 units per milliliter, or about 0.1-20 units per milliliter, and most preferably at a concentration of about 20 units per milliliter. Particularly preferred 3' exo⁺ polymerases include, but are not limited

to, VENTTM, *Pfu*, *Pwo*, *Tne*, *Kod* and *Tma*, and most preferably DEEPVENTTM, DNA polymerases, which should be added to the mixtures in sufficient quantity to give a final working concentration of about 0.0002-200 units per milliliter, about 0.002-100 units per milliliter, about 0.002-20 units per milliliter, about 0.002-2.0 units per milliliter, about 0.002-1.6 units per milliliter, about 0.002-0.8 units per milliliter, about 0.002-0.4 units per milliliter, or about 0.002-0.2 units per milliliter, most preferably at concentrations of about 0.40 units per milliliter. These thermostable DNA polymerases are available commercially, for example from Life Technologies, Inc. (Rockville, Maryland), New England BioLabs (Beverly, Massachusetts), Finnzymes Oy (Espoo, Finland), Stratagene (La Jolla, California), Boehringer Mannheim Biochemicals (Indianapolis, Indiana) and Perkin-Elmer Cetus (Norwalk, Connecticut). The mixtures of the compositions of the invention and the 3' *exo*⁻ and 3' *exo*⁺ polymerases may be used in the methods of the invention to result in enhanced sensitivity of detection, and yield, of large RT-PCR products.

It will be readily apparent to one of ordinary skill in the relevant arts that other suitable modifications and adaptations to the methods and applications described herein are obvious and may be made without departing from the scope of the invention or any embodiment thereof. Having now described the present invention in detail, the same will be more clearly understood by reference to the following examples, which are included herewith for purposes of illustration only and are not intended to be limiting of the invention.

Example 1: Inhibition of RT-PCR by RT

To examine inhibition of RT-PCR amplification by RT, CAT RNA was used as a template. RT-PCR reactions were conducted in a 50 μ l final volume in

PCR buffer (20 mM Tris-HCl, 50 mM KCl) or ELONGASE buffer (60 mM Tris-SO₄ (pH 9.1), 18 mM (NH₄)₂SO₄; total sulfur concentration approximately 23 mM) containing 20 units of M-MLV(H⁻) RT, 1 mM dithiothreitol (DTT), 0.2 mM each of sense and antisense primers, 0.2 mM dNTPs, 1.25 mM MgCl₂,
5 2 units of *Taq* and various amounts of CAT mRNAs (0, 10, 10², 10³, 10⁴, 10⁵, 10⁶ or 10⁷ copies per reaction). RT-PCR conditions were one cycle of 45°C for 30 minutes and 94°C for 2 minutes, followed by 40 cycles of 94°C for 15 seconds/60°C 30 seconds and then 72°C for 5 minutes.

Upon analysis of the amplification products by 1.5% agarose gel
10 electrophoresis (Figure 1), significant amplification of the 500 bp target sequence was observed in reactions carried out in ELONGASE buffer using 10⁶ or 10⁷ copies of CAT mRNA template (Figure 1, lanes 8 and 9). In contrast, no significant PCR product was observed for reactions carried out in standard PCR buffer at all template concentrations (Figure 1, lanes 18, 19). These results indicate that the
15 presence of RT in PCR reaction mixtures inhibits the amplification reaction, but that this inhibition is at least partially relieved using ELONGASE buffer.

Example 2: Role of Sulfur in Relief of RT Inhibition in PCR Amplification

To determine if the sulfate ion in ELONGASE buffer might be a key
20 component for the relief of RT inhibition observed in Example 1, various reaction parameters such as pH, ionic conditions and buffer composition were studied in detail. RT-PCR reactions were carried out in a 50 µl final volume containing 1 mM DTT, 0.2 mM dNTPs, 1.5 mM MgSO₄, 0.2 mM each of sense and antisense human β-actin primers, 1 pg of total HeLa RNA template, 2 units of *Taq*
25 DNA polymerase and 10 units M-MLV(H⁻) RT in buffered salt solutions comprising various ionic and buffer conditions. RT-PCR conditions were 30 minutes at 45°C and 2 minutes at 94°C, followed by 40 cycles of 94°C for 15 seconds/55°C for 30 seconds/68°C for 90 seconds, and one final extension for 5

minutes at 72°C. The ability to detect an amplified 1,026-bp RT-PCR product from 1 pg of total HeLa RNA was used as an assessment of the amplification success under the specific reaction conditions.

5 Upon analysis of 1,026-bp b-actin RT-PCR products in 1% agarose gel electrophoresis, the results shown in Tables 1-7 were obtained.

Table 1: Compositions comprising Tris-HCl (pH 8.5-9.3) demonstrated a sensitivity of about 1 pg total HeLa RNA when 18 mM (NH₄)₂SO₄ was present. However, this increased sensitivity was obtained over a broader pH range (pH 7.8-9.3) when Tris-SO₄ buffer was used in place of Tris-HCl.

Table 1. Optimal pH in Tris-HCl and Tris-SO₄ Buffers.

pH	7.5	7.8	8.0	8.3	8.5	8.8	9.0	9.3	9.5
Tris-HCl, 60 mM ¹	+	+	+	+	+	+	+	+	+
(NH ₄) ₂ SO ₄ , 18 mM	+	+	+	+	+	+	+	+	+
Sensitivity (Yield of PCR Product)	-	-	-	-	+	-	++	+	-

pH	7.5	7.8	8.0	8.3	8.5	8.8	9.0	9.3	9.5
Tris-SO ₄ , 60 mM	+	+	+	+	+	+	+	+	+
(NH ₄) ₂ SO ₄ , 18 mM	+	+	+	+	+	+	+	+	+
Total Sulfur Concentration (mM) ²	41	38	35	32	30	26	23	22	21
Sensitivity (Yield of PCR Product)	-	+	+	+	+	+	++	+	-

¹The pH in the Tris-HCl reaction mixture was adjusted using HCl. Therefore, no sulfur was contributed via pH adjustment, and the sulfur concentration for each pH tested was approximately 18 mM.

²The pH in the Tris-SO₄ reaction mixture was adjusted using sulfuric acid. Therefore, the addition of sulfuric acid increased the sulfur concentration to approximately that shown.

Table 2: In order to detect the 1,026-bp RT-PCR product in compositions comprising Tris-HCl buffer, the inclusion of 20 mM (NH₄)₂SO₄ in the compositions was essential. However, if Tris-SO₄ buffer (20-80 mM, pH 8.0-9.0) was used in place of Tris-HCl, the inclusion of (NH₄)₂SO₄ was not required.

Table 2. Requirement for Sulfur and Potassium.

Requirement for Sulfur and Potassium.																			
pH		9.0					8.5					8.0							
		+	+	+	+	+	+	+	+	+	+	+	+	+	+				
Tris-HCl, 60 mM		0	10	20	40	60	80	0	10	20	40	60	80	0	10	20	40	60	80
(NH ₄) ₂ SO ₄ , mM ¹		0	10	20	40	60	80	0	10	20	40	60	80	0	10	20	40	60	80
Sensitivity (Yield of PCR Product)		-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH		9.0					8.5					8.0							
		20	40	60	80	100	20	40	60	80	100	20	40	60	80	100			
Tris-SO ₄ , mM		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
KCl, 40 mM		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Total Sulfur Concentration (mM) ²		20	21	23	25	26	22	26	30	34	38	24	29	35	41	46			
Sensitivity (Yield of PCR Product)		-	-	+	+	-	+	+	+	+	-	+	-	-	-	-	-	-	-

and the sulfur concentration for each pH tested

¹The pH in the Tris-HCl reaction mixture was adjusted using HCl. Therefore, no sulfur was contributed via pH adjustment, and the sulfur concentration for each pH tested was approximately 18 mM.

²The pH in the Tris-SO₄ reaction mixture was adjusted using sulfuric acid. Therefore, the addition of sulfuric acid increased the sulfur concentration to approximately that shown.

Table 3: Requirement for sulfur for sensitive detection of 1,026 bp RT-PCR product was also demonstrated by use of taurine ($\text{NH}_2\text{CH}_2\text{SO}_3\text{H}$), which contains sulfur ion. Taurine relieved the RT-mediated inhibition of RT-PCR about as well as did ammonium sulfate.

Table 3. Requirement for Sulfur.

Tris-HCl, 60 mM (pH 9.0)	+	+	+	+	+	+	+	+	+	+
[Taurine], mM	0	10	20	40	60	0	0	0	0	0
[Ammonium Sulfate], mM	0	0	0	0	0	0	1 0	20	4 0	60
Sensitivity (yield of PCR product)	-	+	++	++ +	++ +	-	+	++ +	-	-

Table 4: The increased detection sensitivity of the Tris- SO_4 buffer system shown in Table 2 (60 mM, pH 8.5-9.0) could be further enhanced by the addition of 20-40 mM KCl, indicating that potassium-containing molecules not only were suitable substitutes for sulfur-containing molecules in the present compositions, but may also enhance the sensitivity of the RT-PCR reaction in their own right.

Table 5: Similar detection sensitivity and further enhancement by the addition of KCl was obtained in the Tris-aurine buffer system.

Table 4. Role of Potassium in Suboptimal Concentrations of Sulfur.

pH	9.0						8.5						8.0					
	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Tris-SO ₄ , 60 mM	0	10	20	40	60	80	0	10	20	40	60	80	0	10	20	40	60	80
(NH ₄) ₂ SO ₄ , mM	0	10	20	40	60	80	0	10	20	40	60	80	0	10	20	40	60	80
Sensitivity (Yield of PCR Product)	-	-	++	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-
pH	9.0						8.5						8.0					
	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Tris-SO ₄ , 60 mM	0	20	40	60	80	100	0	20	40	60	80	100	0	20	40	60	80	100
KCl, mM	0	20	40	60	80	100	0	20	40	60	80	100	0	20	40	60	80	100
Sensitivity (Yield of PCR Product)	-	-	+	+	+	-	-	-	+++	+++	+++	-	-	-	-	-	-	-

Table 5. Requirement for Sulfur and Potassium.

[Tris- taurine], mM (pH 8.9)	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
[Ammonium sulfate], mM	0	10	20	40	60	60	60	60	60	60	60	60	60	60	60	60	60	60
[Taurine], mM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60
[KCl], mM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sensitivity (yield of PCR product)	-	+++	+++	-	-	-	+	++	+++	+++	60	+	++	-	++	+	++	+++

Table 6: The addition of NH_4Cl in place of $(\text{NH}_4)_2\text{SO}_4$ in the present compositions did not relieve the RT-mediated inhibition of RT-PCR, indicating that sulfur-containing molecules are key components for the relief of RT inhibition in RT-PCR.

Table 6. Requirement for Sulfur.

Buffer Composition (Additive to Tris-HCl, 60 mM)	Detection Sensitivity (Yield of PCR Product)	
	$(\text{NH}_4)_2\text{SO}_4$, 20 mM	NH_4Cl , 40 mM
Magnesium Sulfate, 1.5 mM	+	-
Magnesium Acetate, 1.5 mM	+	-
Magnesium Chloride, 1.5 mM	+	-

Table 7: Requirement for sulfur ion for relief of RT-mediated inhibition of PCR was less stringent in Tris-acetate buffer systems than in Tris-sulfate buffer systems. In the Tris-acetate buffer system, RT-PCR products of 1,026 bp size were able to be observed even in the absence of sulfur ions.

Table 7: Requirement for Sulfur and Effect of Buffers.

Tris- SO_4 , 60 mM (pH 9.0)	+	+	+	+	+	-	-	-	-	-
Tris-acetate, 60 mM (pH 8.4)	-	-	-	-	-	+	+	+	+	+
$[(\text{NH}_4)_2\text{SO}_4]$, mM	0	10	20	40	80	0	10	20	40	80
Sensitivity (yield of PCR product)	-	++	+++	-	-	+	++	+++	-	-

Example 3: Role of Bovine Serum Albumin (BSA) in RT-PCR

To investigate other reaction components which might relieve the RT-mediated inhibition of RT-PCR, BSA was added to the present compositions. Compositions were formulated comprising increasing amounts of M-MLV(H⁺) RT (from 10 units to 260 units) and various amount of BSA, and these compositions used in RT-PCR reactions. Reactions were conducted in a 50 µl final volume containing 60 mM Tris-SO₄ (pH 9.1), 18 mM (NH₄)₂SO₄, 0.2 mM dNTPs, 1.2 mM MgSO₄, 0.02 mM DTT, 0.2 mM each of human β-actin CAT mRNA sense and antisense primers, 2 units of *Taq* DNA polymerase and 100 pg of total HeLa RNA template for β-actin amplification, or 10⁵ copies of total HeLa RNA template for CAT amplification. RT-PCR conditions were 30 minutes at 45°C and two minutes at 94°C, followed by 40 cycles of 94°C for 15 seconds/55°C for 30 seconds/68°C for 90 seconds, and then one final extension of five minutes at 72°C.

Upon analysis of the 1,026-bp β-actin RT-PCR products in 1% agarose gel electrophoresis (Figure 2A), RT inhibition was not observed with 10 units of RT, but increasing amounts of RT (135 units-260 units) inhibited RT-PCR completely. However, such RT inhibition was relieved by the addition of 200-1000 ng of BSA per reaction (*i.e.*, a final BSA concentration of about 4-20 µg/ml). Similar results were obtained from the analysis of the 653-bp CAT RT-PCR products (Figure 2B), where only a slightly higher amount of BSA (300-1000 ng per reaction *i.e.*, a final BSA concentration of about 6-20 µg/ml) was required for the relief of RT inhibition. Together, these results indicate that the incorporation of proteins such as BSA into the compositions of the invention may assist in overcoming the inhibition of RT-PCR caused by RT.

Example 4: Performance of M-MLV, AMV, M-MLV(H⁻) for RT-PCR in Sulfur- and BSA-containing Buffer

To study the performance of various RTs in RT-PCR, AMV-RT, M-MLV-RT, and M-MLV(H⁻) RT were used in the present compositions. RT-PCR reactions for M-MLV-RT and M-MLV H⁻ RT (Superscript II) were conducted in a 50 µl final volume containing 60 mM Tris-SO₄ (pH 9.1), 18 mM (NH₄)₂SO₄, 0.2 mM dNTPs, 250 ng BSA, 1.0 mM DTT, 0.2 mM each of CAT sense and antisense primers, 2 units of *Taq* DNA polymerase, 1.5 mM MgSO₄, and various amount of CAT RNA template (0, 10³, 10⁴ or 10⁵ copies per reaction). The compositions containing AMV-RT were the same except that they lacked BSA. For each reaction, 5 units each of AMV-RT, M-MLV-RT or M-MLV(H⁻) RT were used. RT-PCR cycling conditions were 30 minutes at 45°C and 2 minutes at 94°C, followed by 40 cycles of 94°C for 15 seconds/60°C for 30 seconds, and then a final extension of five minutes at 72°C.

As shown in Figure 3, upon analysis of 500-bp CAT RT-PCR products in 1.5% agarose gel electrophoresis the reactions performed with AMV-RT, M-MLV-RT, and M-MLV(H⁻)-RT demonstrated efficient and sensitive RT-PCR product yield, with no inhibition of the RT-PCR reactions observed under any of the reaction conditions.

Example 5: RT-PCR Amplification of Long Nucleic Acid Templates

Having demonstrated the simplicity and sensitivity of the present methods in RT-PCR amplification of templates up to 3.5 kb in size, the efficacy of the invention in amplifying mRNAs up to 8.9 kb was examined.

Total HeLa RNA was isolated with TRIzol® Reagent (Life Technologies, Inc.; Rockville, Maryland) and amplified as above. To examine possible temperature effects, identical reactions were assembled and incubated at 45°C to 55°C in duplicate. The total HeLa RNA used varied from 1 ng to 100 ng

depending on the abundance of the mRNA. After the RT incubation for 30 minutes, the reactions were incubated at 94°C for two minutes, followed by 40 cycles of 94°C for 15 seconds, 55°C for 30 seconds and 68°C for 60 seconds, followed by a final 68°C extension for five minutes.

5 For larger RT-PCR products, the magnesium concentration was increased to 1.8 mM from the standard 1.5 mM, and 1 µl of ELONGASE Enzyme Mix (Life Technologies, Inc.; Rockville, Maryland) was added to each reaction. The final 50 µl reaction consisted of 1X ELONGASE buffer with 1.8 mM MgSO₄ and other salts, 200 µM of each dNTP, 2 µg/ml BSA, 0.2 µM of primers (GIBCO BRL Custom Primers; Life Technologies, Inc., Rockville, Maryland), 100 ng of total
10 HeLa RNA, 1 µl of the RT/*Taq* enzyme mix of the invention and 1 µl of ELONGASE Enzyme Mix. For the experiments using the same template of primers, a master mix of buffer, enzyme mixes, and primers or template was made to ensure consistency. The samples were incubated at 50°C for 30 minutes and
15 then 94°C for two minutes. Amplification was performed with 40 cycles of 94°C for 15 seconds, 58°C for 30 seconds and 68°C for six to nine minutes (one minute/kb). The RT-PCR products were resolved and visualized on 0.8 or 1.0 % (w/v) agarose-TAE gels containing ethidium bromide.

Temperature of the RT reaction. SUPERScript II RT has improved
20 temperature stability compared to M-MLV-RT (Gerard, G., *et al.*, *FOCUS* 14:91 (1992)). To test the effect of temperature on RT-PCR products, 36 primer sets (representing different genes from human, rat, plant, and one *in vitro* transcript) were examined. As shown in Figure 4, substantial product yield and specificity were observed at 45°C for many of the fragments examined; increased incubation
25 temperature did not result in increased yield or specificity. This result, however, was dependent upon the specific template and primer chosen (Figure 5): for some template-primer combinations, the smearing of bands caused by mispriming that was characteristic of RT reactions conducted at 45°C disappeared with increased temperature (Figure 5; lanes 1-6), while in some cases a significant increase in

product yield was observed when the RT reactions were conducted at elevated temperatures (Figure 5; lanes 7-12).

Long RT-PCR Products. For studies of full-length coding sequences or for amplification of long segments of RNA, the use of the compositions of the present invention supplemented with ELONGASE Enzyme Mix was tested. As shown in Figure 6, the present system and Supplier A's kit were able to amplify a 2.8-kb product from 100 ng, but not from 10 ng, of total RNA. The addition of ELONGASE Enzyme Mix to the present system not only increased the product yield with 100 ng of total RNA, but also increased the sensitivity to allow amplification of long templates from 10 ng total RNA (Figure 6; lanes 7-12). In contrast, Supplier A's kit was not able to amplify the 2.8-kb target from 10 ng of total RNA (Figure 6; lanes 13-18) even though it contained a polymerase enzyme mix designed for long templates.

The compositions and methods of the invention were also found to be useful in amplifying large (>3-5 kb) RT-PCR products. As shown in Figure 7, the compositions of the present invention, when supplemented with ELONGASE Enzyme Mix, produced RT-PCR products up to 8.9 kb in size. The ladder of bands observed upon amplification with these compositions is not uncommon for long RT-PCR, and the variation in product yields may be partially due to the use of different primer sets. These results demonstrate that the addition of ELONGASE Enzyme Mix to the present compositions makes it possible to amplify long and rare mRNAs directly from total RNA preparations by the methods of the invention. Further, the thermostability of SUPERScript II RT, facilitating RT-reactions at temperatures of up to 55°C, can increase the specificity and product yield for some templates and primer sets.

Having now fully described the present invention in some detail by way of illustration and example for purposes of clarity of understanding, it will be obvious to one of ordinary skill in the art that the same can be performed by

modifying or changing the invention within a wide and equivalent range of conditions, formulations and other parameters without affecting the scope of the invention or any specific embodiment thereof, and that such modifications or changes are intended to be encompassed within the scope of the appended claims.

- 5 All publications, patents and patent applications mentioned in this specification are indicative of the level of skill of those skilled in the art to which this invention pertains, and are herein incorporated by reference to the same extent as if each individual publication, patent or patent application was specifically and individually indicated to be incorporated by reference.

WHAT IS CLAIMED IS:

1. A method for amplifying a nucleic acid molecule, said method comprising
 - (a) mixing an RNA template with a composition comprising a
5 Moloney murine leukemia virus (M-MLV) reverse transcriptase, one or more DNA polymerases and one or more sulfur-containing molecules at a concentration of at least 18 mM sulfur, to form a mixture; and
 - (b) incubating said mixture under conditions sufficient to amplify a DNA molecule complementary to all or a portion of said RNA template.
- 10 2. The method of claim 1, wherein said composition further comprises one or more acetate-containing molecules.
3. A method for amplifying a nucleic acid molecule, said method comprising
 - (a) mixing an RNA template with a composition comprising a
15 Moloney murine leukemia virus (M-MLV) reverse transcriptase, one or more DNA polymerases and one or more acetate-containing molecules at a concentration of about 1 mM to about 500 mM, to form a mixture; and
 - (b) incubating said mixture under conditions sufficient to amplify a DNA molecule complementary to all or a portion of said RNA template.
- 20 4. The method of claim 1 or claim 3, wherein said DNA polymerase is *Taq* DNA polymerase.
5. The method of claim 1 or claim 3, wherein said DNA polymerases comprise a first DNA polymerase having 3' exonuclease activity and a second DNA polymerase having substantially reduced 3' exonuclease activity.

6. The method of claim 1 or claim 3, wherein the unit ratio of said reverse transcriptase to said DNA polymerases is from about 0.2:2 to about 500:2.

7. The method of claim 6, wherein said ratio is from about 0.5:2 to about 250:2.

5 8. The method of claim 6, wherein said ratio is greater than 3:2.

9. The method of claim 1, wherein said sulfur concentration is at least 19 mM.

10. The method of claim 1, wherein said sulfur concentration is about 20 mM to about 50 mM.

10 11. The method of claim 1, wherein the source of said sulfur is a sulfur-containing buffer.

12. The method of claim 1, wherein the source of said sulfur is a sulfur-containing salt.

15 13. The method of claim 11, wherein said sulfur-containing buffer is TRIS-sulfate (tris[$\{\text{hydroxymethyl}\}$]aminomethane] sulfate).

14. The method of claim 12, wherein said sulfur-containing salt is selected from the group consisting of ammonium sulfate, magnesium sulfate and manganese sulfate.

20 15. The method of claim 2 or claim 3, wherein the concentration of said acetate-containing molecule is about 60 mM.

16. The method of claim 2 or claim 3, wherein said acetate-containing molecule is an acetate-containing salt.

17. The method of claim 2 or claim 3, wherein said acetate-containing molecule is an acetate-containing buffer.

5 18. The method of claim 16, wherein said acetate-containing salt is selected from the group consisting of ammonium acetate, magnesium acetate, manganese acetate, sodium acetate and potassium acetate.

10 19. The method of claim 17, wherein said acetate-containing buffer is selected from the group consisting of TRIS-acetate (tris[hydroxymethyl]aminomethane acetate), ADA (N-[2-acetamido]-2-iminodiacetic acid), and imidazole acetate (2-hydroxy-3-[4-imidazolyl]-propionic acid).

20. The method of claim 1 or claim 3, wherein said mixture further comprises one or more nucleotides.

15 21. The method of claim 20, wherein said nucleotides are deoxyribonucleoside triphosphates or derivatives thereof, or dideoxynucleoside triphosphates or derivatives thereof.

20 22. The method of claim 20, wherein said deoxyribonucleoside triphosphates are selected from the group consisting of dATP, dUTP, dTTP, dGTP, and dCTP.

23. The method of claim 1 or claim 3, wherein said mixture further comprises one or more oligonucleotide primers.

24. The method of claim 23, wherein said primer is an oligo(dT) primer.

25. The method of claim 23, wherein said primer is a target-specific primer.

5 26. The method of claim 23, wherein said primer is a gene-specific primer.

27. The method of claim 1 or claim 3, wherein said reverse transcriptase is substantially reduced in RNase H activity.

10 28. The method of claim 1 or claim 3, wherein said DNA polymerases are thermostable DNA polymerases.

29. The method of claim 28, wherein said thermostable DNA polymerases are selected from the group consisting of *Tne*, *Tma*, *Taq*, *Pfu*, *Tth*, *Tfi*, VENT, DEEPVENT, *Pwo*, *Tfi*, and mutants, variants and derivatives thereof.

15 30. The method of claim 5, wherein said DNA polymerase having 3' exonuclease activity is selected from the group consisting of *Pfu*, *Pwo*, DEEPVENT, VENT, *Tne*, *Tma*, *Kod*, and mutants, variants and derivatives thereof.

20 31. The method of claim 5, wherein said DNA polymerase having substantially reduced 3' exonuclease activity is selected from the group consisting of *Taq*, *Tfi*, *Tth*, and mutants, variants and derivatives thereof.

32. The method of claim 1 or claim 3, wherein said incubating step (b) comprises

(a) incubating said mixture at a temperature and for a time sufficient to make a DNA molecule complementary to all or a portion of said RNA template; and

(b) incubating said DNA molecule complementary to said RNA template at a temperature and for a time sufficient to amplify said DNA molecule.

33. The method of claim 32, wherein said first step comprises incubating said mixture at a temperature from about 35°C to about 60°C.

34. The method of claim 32, wherein said second step comprises thermocycling.

35. The method of claim 34, wherein said thermocycling comprises alternating heating and cooling of the mixture sufficient to amplify said DNA molecule.

36. The method of claim 35, wherein said thermocycling comprises alternating from a first temperature range of from about 90°C to about 100°C, to a second temperature range of from about 45°C to about 75°C.

37. The method of claim 36, wherein said second temperature range is from about 65°C to about 75°C.

38. The method of claim 34, wherein said thermocycling is performed greater than 10 times.

39. The method of claim 34, wherein said thermocycling is performed greater than 20 times.

40. The method of claim 1 or claim 3, wherein said reverse transcriptase is SuperScript I or SuperScript II.

5 41. The method of claim 1 or claim 3, wherein said amplification is not substantially inhibited.

42. A method for amplifying a nucleic acid molecule comprising:
(a) mixing an RNA template with a composition comprising a
Moloney murine leukemia virus (M-MLV) reverse transcriptase, one or more
10 DNA polymerases, one or more sulfur-containing molecules and one or more
potassium-containing molecules, to form a mixture; and
(b) incubating said mixture under conditions sufficient to
amplify a DNA molecule complementary to all or a portion of said RNA template.

43. The method of claim 42, wherein said composition further
15 comprises one or more acetate-containing molecules.

44. A method for amplifying a nucleic acid molecule comprising:
(a) mixing an RNA template with a composition comprising a
Moloney murine leukemia virus (M-MLV) reverse transcriptase, one or more
DNA polymerases, one or more acetate-containing molecules and one or more
20 potassium-containing molecules, to form a mixture; and
(b) incubating said mixture under conditions sufficient to
amplify a DNA molecule complementary to all or a portion of said RNA template.

45. The method of claim 42 or claim 44, wherein said reverse transcriptase is substantially reduced in RNase H activity.
46. The method of claim 42 or claim 44, wherein said DNA polymerases are selected from the group consisting of *Tne*, *Tma*, *Taq*, *Pfu*, *Tth*, *Tfi*, VENT, DEEPVENT, *Pwo*, *Tfl*, and mutants, variants and derivatives thereof.
47. A method for amplifying a nucleic acid molecule comprising:
- (a) contacting an RNA template with a mixture comprising a Moloney murine leukemic virus (M-MLV) reverse transcriptase and one or more DNA polymerases, wherein the unit ratio of said reverse transcriptase to said DNA polymerases is greater than 3:2, and
- (b) incubating said mixture under conditions sufficient to amplify a DNA molecule complementary to all or a portion of said RNA template.
48. A composition comprising a Moloney murine Leukemic virus (M-MLV) reverse transcriptase, one or more DNA polymerases and at least 18 mM sulfur.
49. The composition of claim 47, further comprising one or more acetate-containing molecules.
50. A composition comprising a Moloney murine Leukemic virus (M-MLV) reverse transcriptase, one or more DNA polymerases, and one or more acetate-containing molecules.
51. The composition of claim 49 or claim 50, wherein the concentration of said one or more acetate-containing molecules is about 1 mM to about 500 mM.

52. The composition of claim 51, wherein the concentration of said one or more acetate-containing molecules is about 60 mM.

53. A composition comprising a Moloney murine Leukemic virus (M-MLV) reverse transcriptase, one or more DNA polymerases, one or more sulfur-containing molecules, and one or more potassium-containing molecules.

5

54. The composition of claim 53, further comprising one or more acetate-containing molecules.

55. A composition comprising a Moloney murine Leukemic virus (M-MLV) reverse transcriptase, one or more DNA polymerases, one or more acetate-containing molecules, and one or more potassium-containing molecules.

10

56. A composition comprising a Moloney murine leukemic virus (M-MLV) reverse transcriptase and one or more DNA polymerases, wherein the unit ratio of said reverse transcriptase to said DNA polymerases is greater than about 3:2.

Figure 1

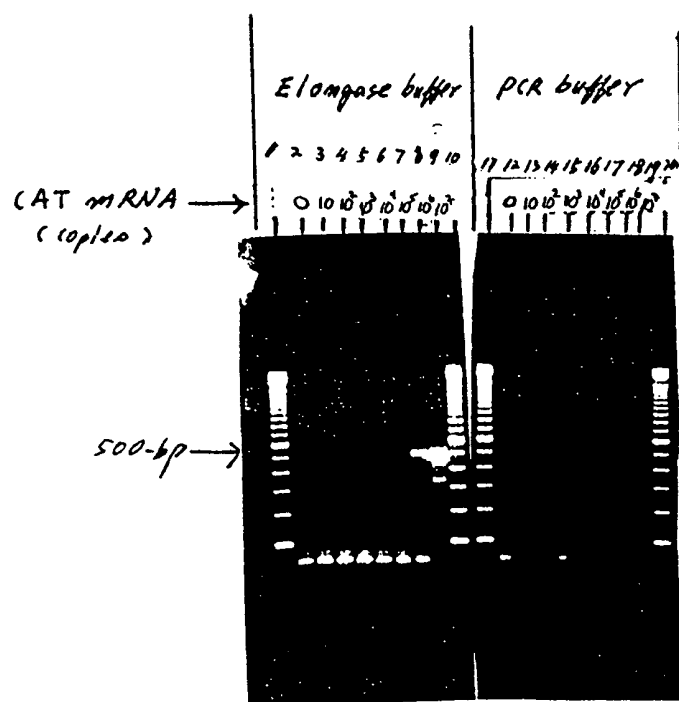


Figure 2A

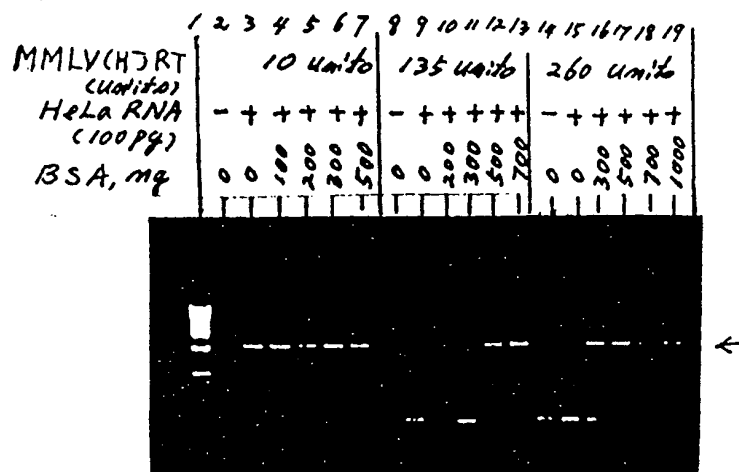


Figure 2B

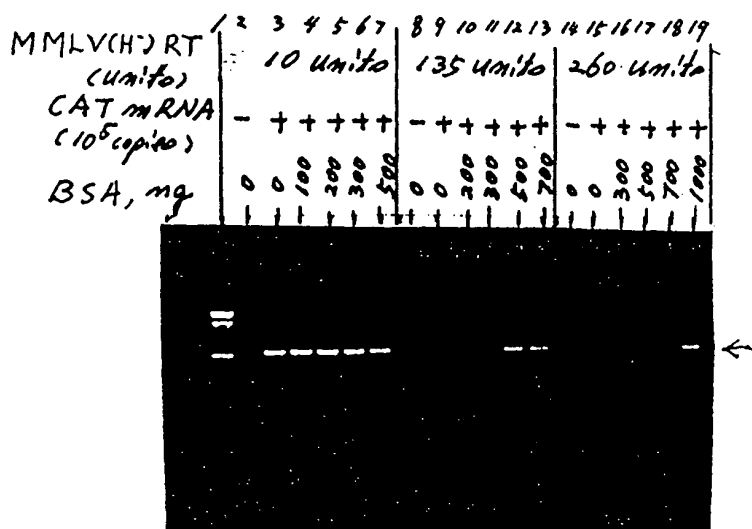
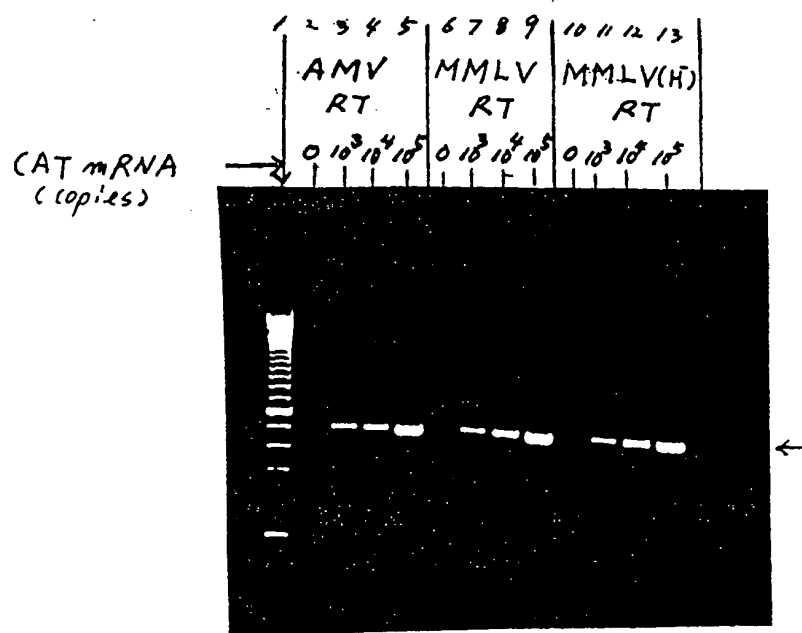


Figure 3



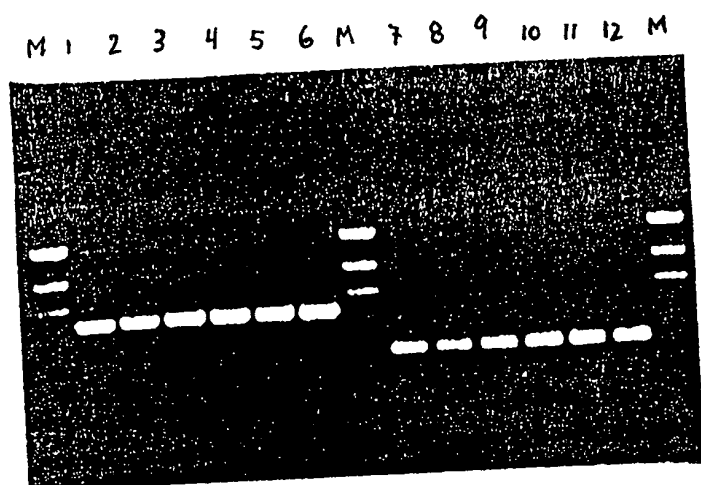


Figure 4.

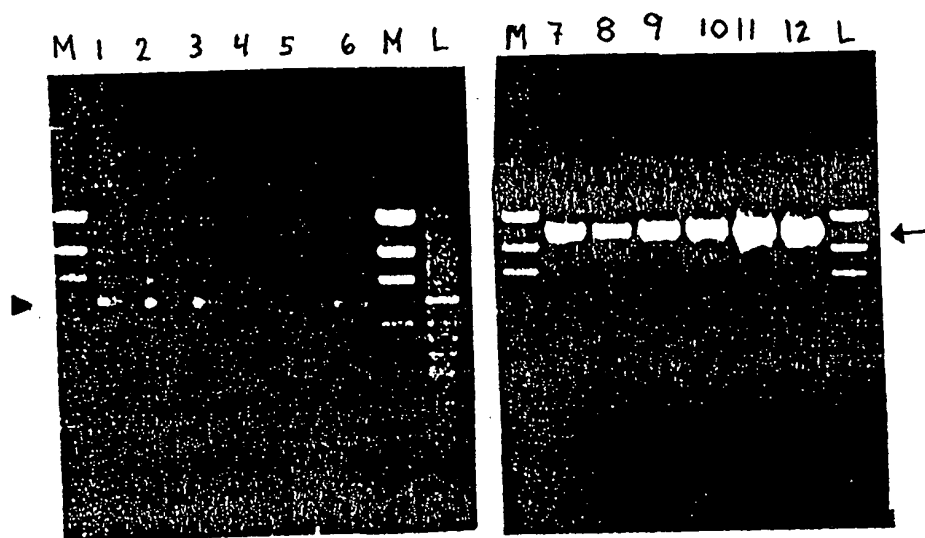


Figure 5.

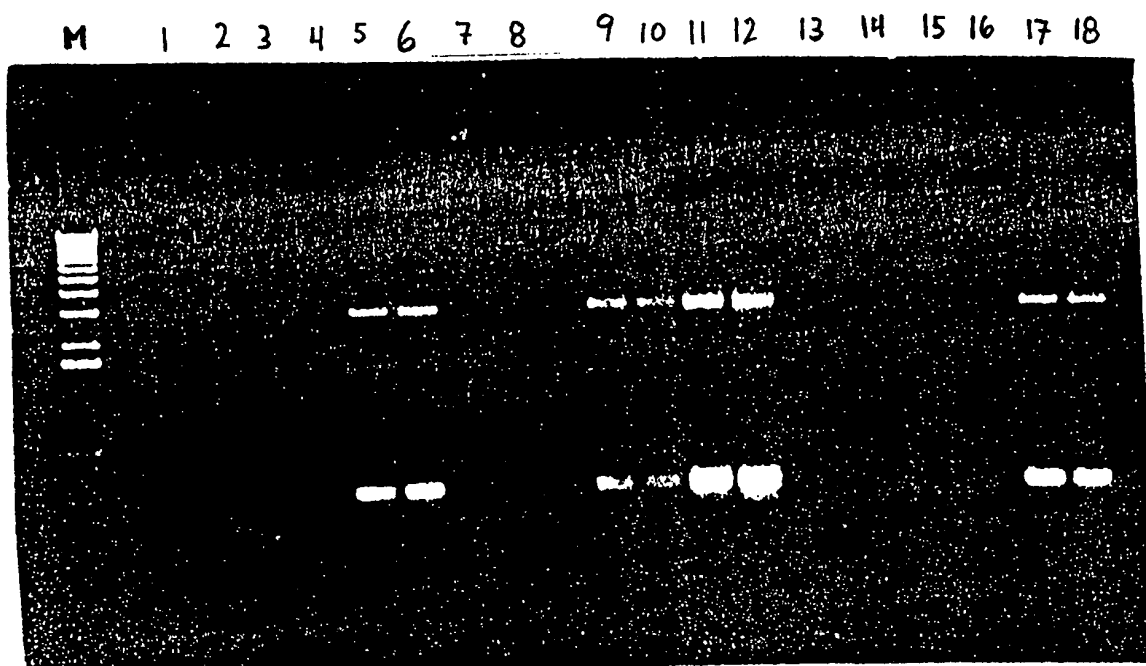


Figure 6.

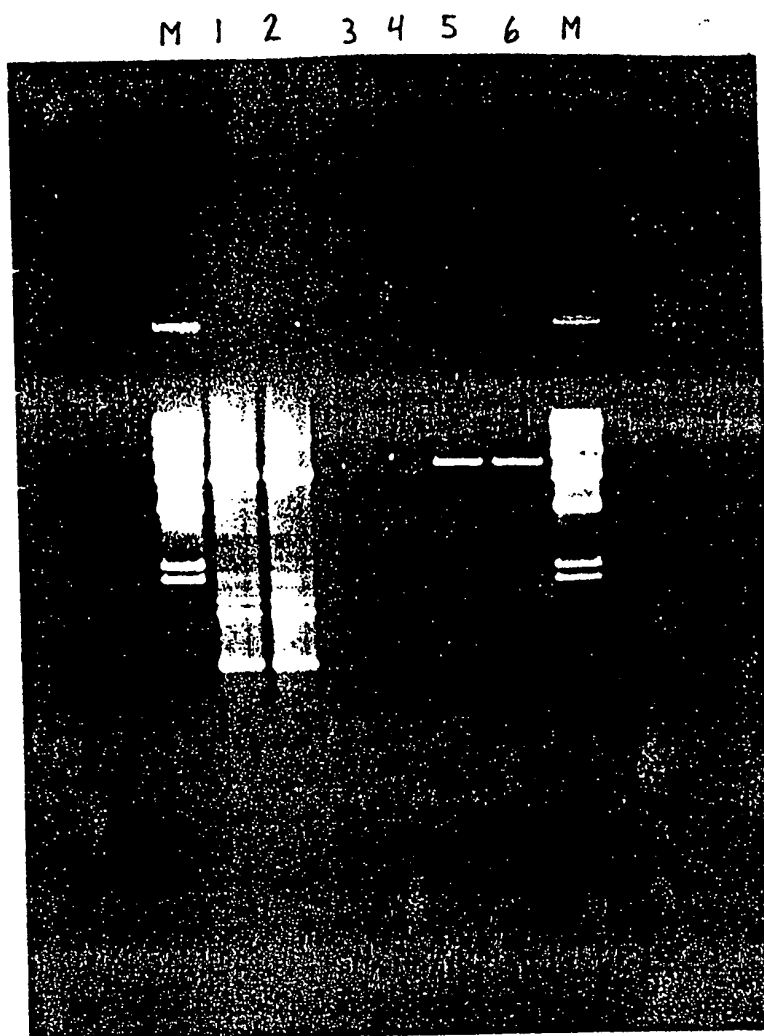


Figure 7.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/06581

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : C12Q 1/68; G01N 33/53; C12P 19/34; C07H 21/02; C12N 15/00

US CL : 435 6,7,1,91,1,91,2; 536 24,2,24,3; 935 77,78

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 435 6,7,1,91,1,91,2; 536 24,2,24,3; 935 77,78

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Please See Extra Sheet.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	SELLNER et al. Reverse Transcriptase inhibits Taq Polymerase Activity. Nucleic Acids Research. 1992, Vol. 20, No. 7, pages 1487-1490, especially page 1488.	1-56
Y	AATINSKI et al. A Coupled One-Step Reverse Transcription PCR Procedure for Generation of Full-Length Open Reading Frames. BioTechniques. 1994, Vol 16, No. 2, pages 282-288, especially page 282.	1-56
Y	PAYAN et al. Detection of Hepatitis C Virus RNA by a reliable optimized single-step reverse transcription polymerase chain reaction. Research Virology. 1995, Vol. 146, No. 5, pages 363-370.	1-56



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
A document defining the general state of the art which is not considered to be of particular relevance	*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
B earlier document published on or after the international filing date	*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*A* document member of the same patent family
O document referring to an oral disclosure, use, exhibition or other means	
P document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

30 JUNE 1998

Date of mailing of the international search report

24 AUG 1998

Name and mailing address of the ISA/US
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/06581

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y,P	US 5,693,517 A (GELFAND et al) 02 December 1997 (12/02/97), see column 1, lines 52-66.	45,29-31
Y	KOKKO et al. Single Step Immunocapture RT-PCR in the Detection of Raspberry Bushy Dwarf Virus. Biotechniques. May 1996, Vol. 20, pages 842-846, especially page 844.	1-56
Y	ANDO et al. One Tube Method of Reverse Transcription-PCR to Efficiently amplify a 3 kilobase Region from the RNA polymerase gene to the Poly (A) tail of Small Round Structured Viruses (Norwalk-Like Viruses). J. of Clinical Microbiology. March 1997, Vol. 35, No. 3, pages 570-577, especially page 571.	1-56
A	CASAS et al. Two Different PCR Assays to Detect Enteroviral RNA in CSF Samples from Patients with Acute Aseptic Meningitis. J. of Med. Virology. 1995, Vol. 47, pages 378-385 especially page 380.	1-56
Y	US 4,683,202 A (MULLIS) 28 July 1987 (07/28/87), see columns 2-7.	20-23,25, 26
A	US 5,556,772 A (SORGE et al) 17 September 1996 (09/17/96), see column 2, line 8-24.	1-56
Y,P	US 5,618,703 A (GELFAND et al) 08 April 1997 (04/08/97), see column 15, lines 20-40.	28-31
Y	TOSH et al. One Tube and One Buffer system of RT-PCR amplification of 1D gene of foot and mouth disease virus field isolates. Acta Virologica. 1997, Vol. 41, pages 153-155 especially page 154.	1-56
Y	Gibco BRL, Product Catalogue and Reference Guide 1995-1996 page 18-12 cDNA Synthesis System product no. 18267-013.	1-56
Y	US 5,561,058 A (GELFAND et al) 01 October 1996 (10/01/96) see column 4, line 20-25 and column 14, line 30-35.	3-8,8,15-18 20-56

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/06581

B. FIELDS SEARCHED

Electronic data bases consulted (Name of data base and where practicable terms used):

APS, DIALOG-scisearch, STM Caplus, medline, biosis, wpids, wpindex, genbank, biotechabs, embase, cancerlit, japio, uspatfull
search terms: Reverse transcript? and PCR or polymerase chain reaction, Moloney, one or single step, sulfur or acetate, Taq, Tnc, Tma, TTh or Kod, TFi or vent or deepvent or Pwo, Pfu.